Behaviour of Preloaded Sandy Soil

by

R.L. Makol*

R.C. Jain**

Introduction

CONSTRUCTION *of multi-storeyed buildings on loose soils and fresh* fills calls for special attention. The conventional type foundation is either not safe or very expensive. Therefore, special type of foundation is considered. Pile or raft foundation is adopted. In many cases, an economical and safe solution is to strengthen the weak soil before the construction of foundation. Abelev (1957) has shown that in loess type of soils, strengthening is more suitable and cheap. In other types of soils, also, strengthening the soil works out cheaper than providing conventional foundations on weak soils.

There are several methods of soil strengthening, Hammond (1955). Mitchell (1970) has reviewed a number of methods. The selection of a method for a particular building depends upon the properties of the soil and the nature and size of the building. Other factors, such as, availability of equipment, materials and labour used in the method also influence the decision.

At Central Building Research Institute, Roorkee a simple method of preloading has been tested, which is applicable to sandy soils and is suitable for three to four storeyed buildings. It is different from the conventional method of preloading, in which the entire site is loaded with loose earth 6 to 8 m height, and sand drains are installed to accelerate the rate of precompression. The operation of deloading involves substantial part of the cost in conventional method.

The CBRI method [Mohan & Jain (1970)] consists of precompression of weak soil in foundation trenches before concreting. The load is applied with a square steel plate and hydraulic jack. The width of the plate is equal to the width of the trench. The reaction for the jack is taken from R.S. Joist (6 m long) installed horizontally over the centre line of the trench. Cross joists and holdfasts are used to anchor the frame to the ground (Figure 1). Several preloading operations, one beside the other, can be done under one setting of the frame. The preloading stress at one location is applied for an hour and released. Four to five preloading operations can be easily done each day.

The method was applied in a series of trenches at a School site in Roorkee. R.C. footings 60 cm wide and 3 m long were cast in these trenches

*Scientist, **Senior Scientific Assistant, Central Building Research Institute, Roorkee.

This paper was received on 27 November 1971. It is open for discussion up to October 1972.

over the soil preloaded to different stresses. Load testing of the foot ings have revealed that bearing capacity of the virgin soil is improved by preloading. The stress corresponding to a settlement of 25 mm was increa sed from 0·77 to 1·53 kg/cm², Makol & Jain (1971 a).

The method was also applied in actual foundations of a double storey school building to be constructed on a fill in Roorkee. The labour, time and cost involved in preloading was recorded, Makol & Jain (1971 b). A saving of 58 percent in the cost of conventional foundation was estimated. To use this method with full confidence in other works also, it was considered necessary to measure its efficacy for very loose soil. This was done in the laboratory on artificially deposited dry river sand using model footings. In this paper, the results of the model study are presented.

Soil

The grain-size distribution of the Solani River sand used is given in Figure 2. The maximum and minimum dry densities of this soil were 1·67 gm/cc and 1·25 gm/cc respectively.

Equipment

The sand was filled in a wooden box of inside dimensions $45 \times 45 \times 25$ cm and was tested in a loading frame shown in Figure 3. The load was applied and maintained constant with the help of hydraulic jack and was measured on a sensitive proving ring. The settlement was measured with dial gauges of 0·01 mm sensitivity. For filling the sand in the box uniformly, rainfall technique was applied. The sieve suspended from a frame is shown in Figure 4. The tests were conducted with model footings shown in Figure 5. The aluminum formers were used to retain the soil on the sides of the trench. Square footings were used to preload the soil and rectangular footings for testing the soil. The widths of square and rectangular footings were 37·5 mm, 50 mm, 62·5 mm and 75 mm. The lengths of rectangular footings were three times the widths of the footings. The lengths and widths of the formers were 4 mm greater than the lengths and widths of respective rectangular footings. The depths of the formers were equal to the widths of the footings.

Sand Deposition

For low relative densities ($<$ 30 percent), sand was filled in the box by simply pouring with a small container. The height of fall was controlled to achieve uniform density. For comparatively higher densities ($>$30 percent), rainfall technique was applied. The sand was filled in layers of 2·5 cm thickness each. The sand was first filled up to a thickness of 15 cm (or more) and levelled. The former was placed exactly in the middle of the box. The sand was again filled on the sides of the former and levelled as shown in Figure 6. A paper was placed on the former during filling and care was taken to avoid the falling of sand in the trench.

Preloading and Testing

Rectangular footing was placed on the virgin soil surface in the trench. The soil below the footing was tested by applying load on it. The load was applied in small increments and the corresponding settlements were measured when the rate of settlement became negligible (0·02 mm/5 minutes). Subsequent tests were done on preloaded soil. Preloading of the soil in the trench was done with the help of square footing in three operations. These

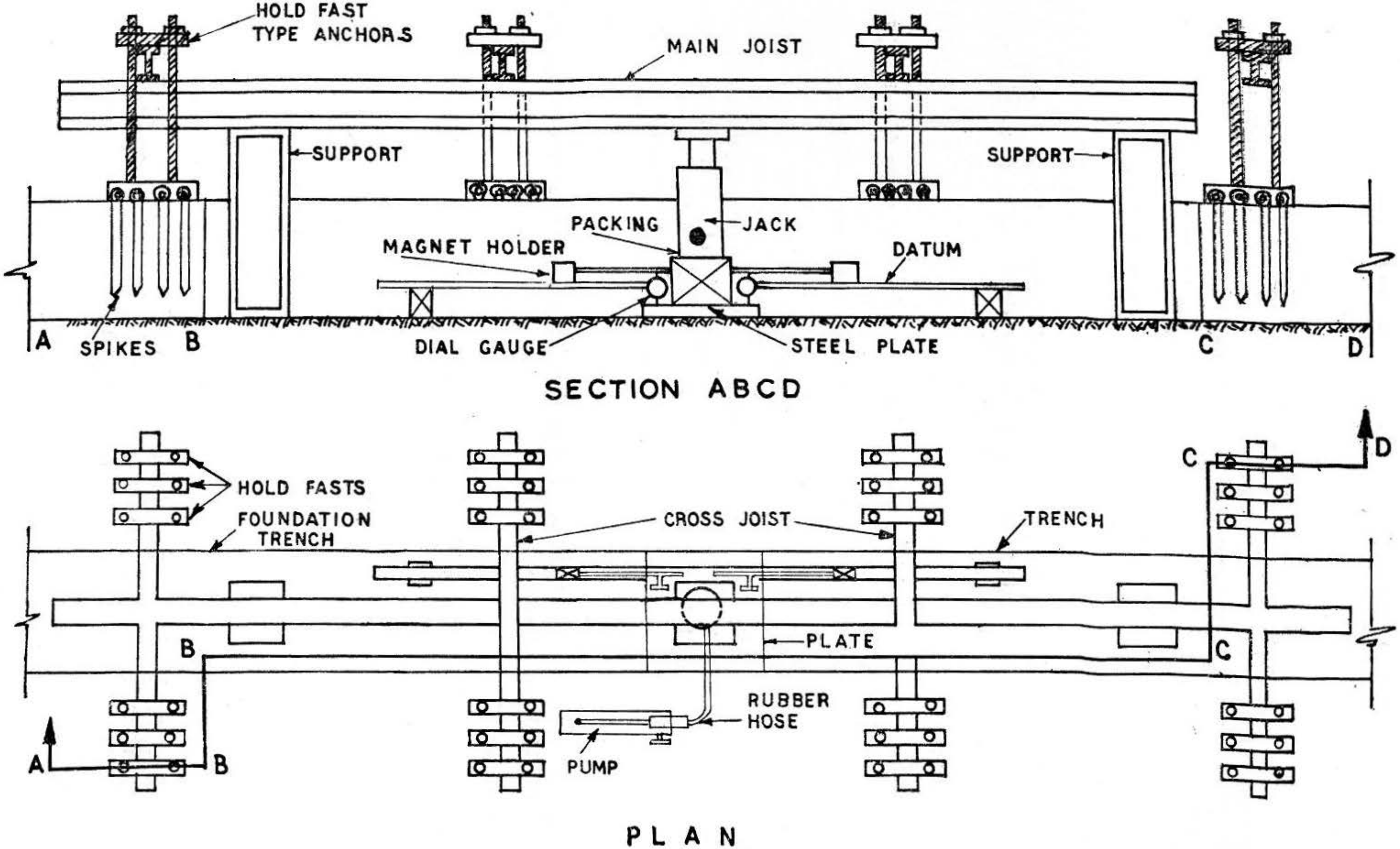

FIGURE 1 : Set-up of equipment used for preloading in trenches.

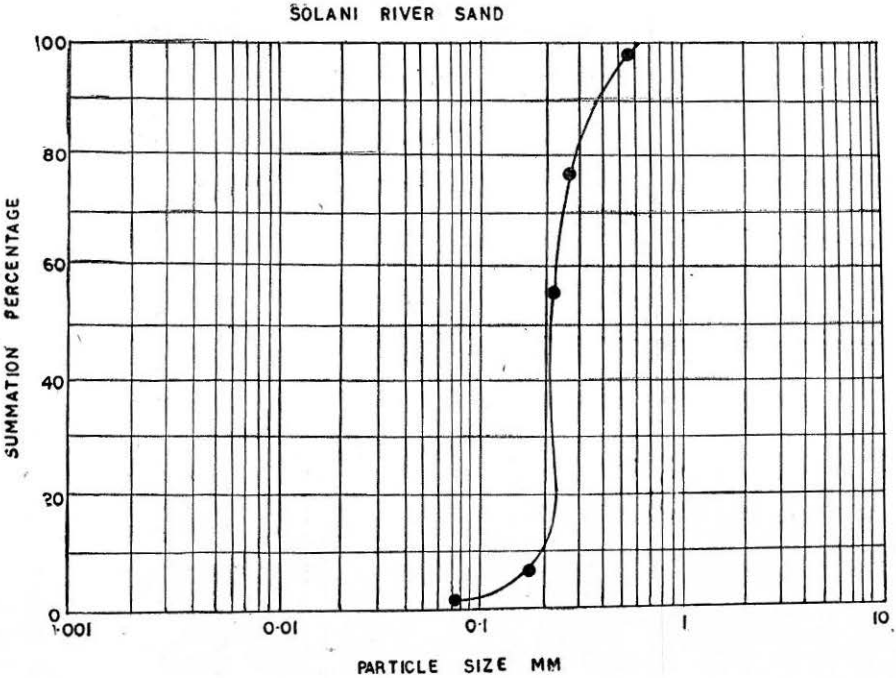

FIGURE 2 : Grain-size distribution of Solani River sand.

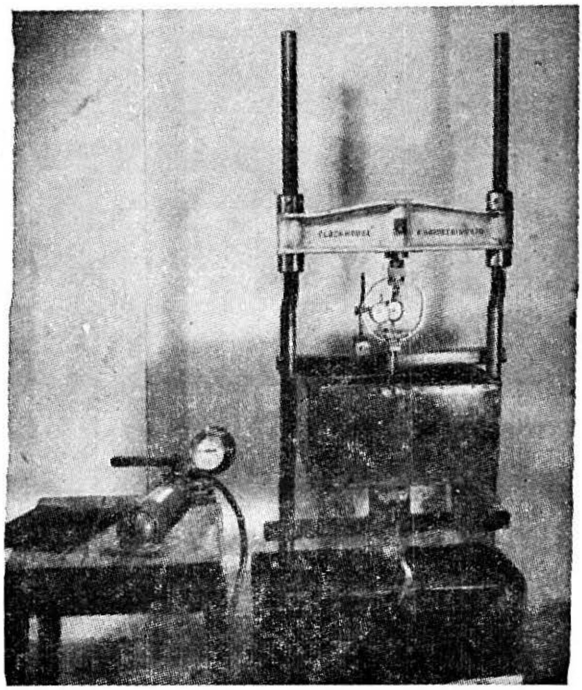

FIGURE 3 : Laboratory loading frame for load testing.

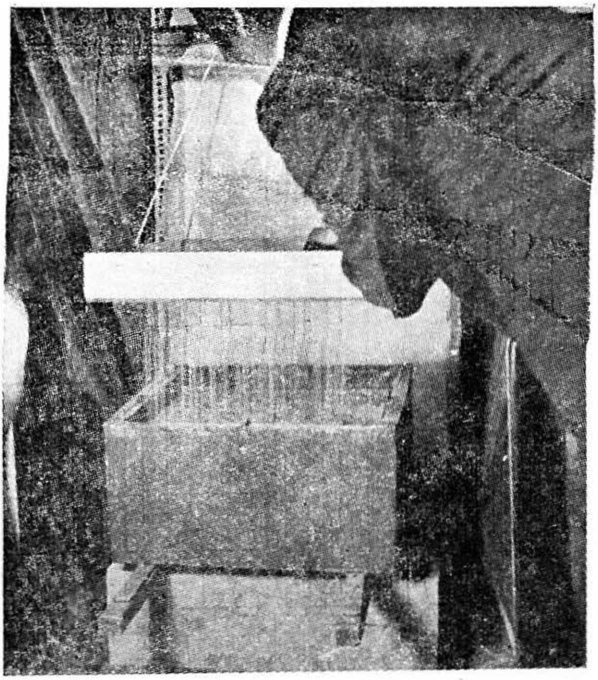

FIGURE 4 : Equipment for depositing the sand by rainfall technique.

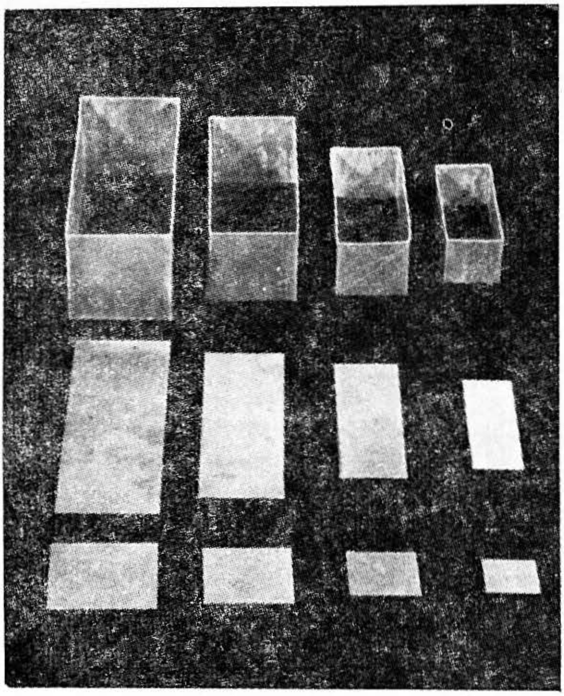

FIGURE 5 : A view of model footings and trenches.

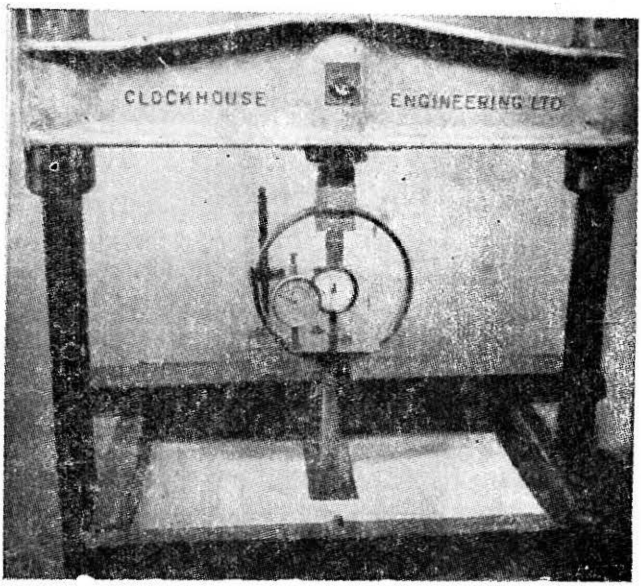

FIGURE 6 : A view of levelled sand surface before testing.

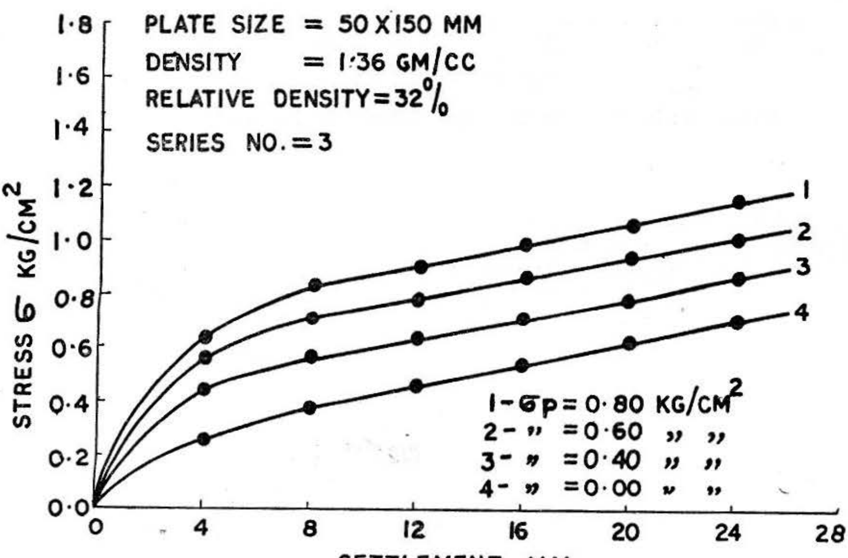

FIGURE 7 : Stress-settlement relation of model tests.

operations were done in the trench, one just beside the other in a line. In one test, the preloading stress in all the three operations was kept a certain constant value. In other tests of the same series on the same dry density of the sand, the preloading stress was varied to other constant values.

Test Programme

In all, nine series of tests were conducted, one with 37·5 mm wide footing, four with 50 mm wide footings and two each with 62·5 and 75 mm wide footings. The value of dry density in each series and the preloading stress in each test are given in Table I.

Discussion of Test Results

Typical stress-settlement results of one series of tests for 50 mm wide footings are given in Figure 7. It was observed that the stress of virgin soil at all the settlements gets improved by preloading. The increase in

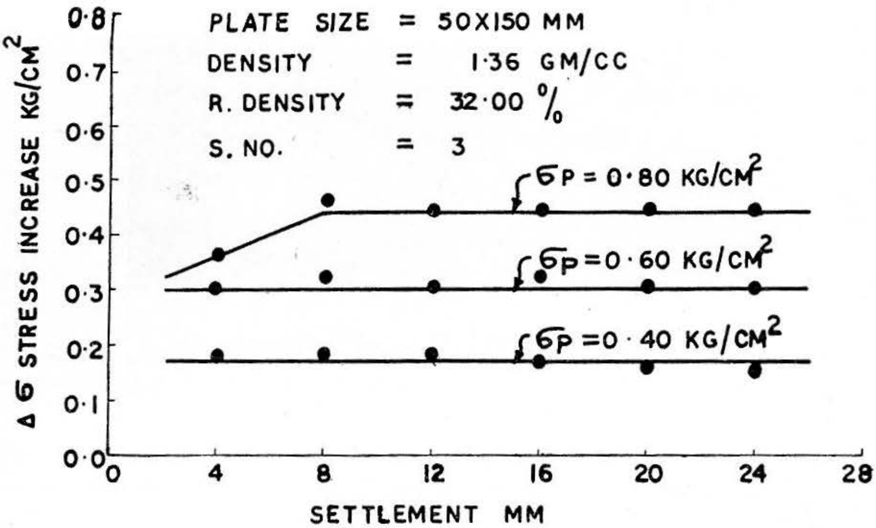

FIGURE 8 : Improvement in stress at different settlements of model fotiongs.

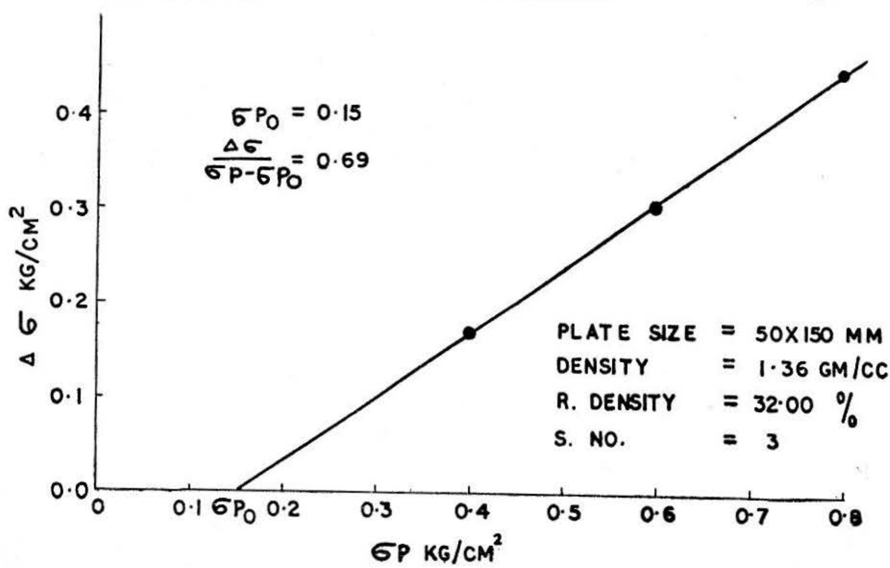

FIGURE 9 : Improvement in stress versus preloading stress.

TABLE I

Test programme for model study.

Sl.No.	Tests No.	Dry density of the soil(gm/cc)	Relative density %	Size of plate tested (mm)	Depth of test (mm)	Preloading stress applied (kg/cm^2)	Remarks
1.	1—5	1·32	21	37·5×112·5	37·5	0·1,0·15,0·20,0·30	
2.	6—9	1·31	18	50×150	50	0·0,0·2,0·3,0·4	
3.	10—13	1·36	32	50×150	50	0·0,0·4,0·6,0·8	
4.	14—17	1·42	48	50×150	50	0·0,0·6,0·8,1·2	
5.	18—21	1·485	63	50×150	50	0·0,0·6,1·2,1·5	
6.	22—26	1·32	21	62·5×187·5	62·5	0·0,0·2,0·3,0·4,0·5	
7.	27—30	1·37	35	62·5×187·5	62·5	0·0,0·2,0·4,0·6	
8.	31—37	1·32	21	75×225	75	0·0,0·1,0·2,0·3,0·4, 0·5,0 6	
9.	38—42	1·37	35	75×225	75	0·0,0·4,0·6,0·8,1·0	

stress ($\triangle\sigma$) at any settlement is the function of the settlement ρ, the initial relative density of the soil R, the preloading stress applied (σp), the width of the footing used B, the depth of the footing D.

$$\triangle\sigma = f(\sigma p, R, \rho, B, D) \qquad ...(1)$$

All tests were done at $D/B=1$. The value of ($\triangle\sigma$) in this study mainly depends upon σp, R and ρ. The value ($\triangle\sigma$) for the series in Figure 7 was plotted against settlement ρ in Figure 8. It was found that $\triangle\sigma$ varies with settlement σ but becomes constant after a settlement of 12 mm. This was found for all the nine series of tests. The constant value of ($\triangle\sigma$) after 12 mm settlement mainly depends upon (σp) and R. The values of $\triangle\sigma$ after 12 mm settlement for the series in Figure 7 were plotted against preloading stress (σp) in Figure 9. It was found that $\triangle\sigma$ varies with preloading stress (σp). The relation is a straight line. The increase in stress was zero or negligible up to a certain value of the preloading stress. This was found by extending the straight line back up to $\triangle\sigma=0$ line. The starting point of the straight line was denoted by (σp_o) and the slope of the line was denoted by the ratio $\triangle\sigma/(\sigma p-\sigma p_o)$. The values of σp_o and the ratio $\triangle\sigma/(\sigma p-\sigma p_o)$ for all the nine series of tests were computed and are given in Table II. The initial density of the soil R was plotted against σp_o in Figure 10 and against the ratio $\triangle\sigma/(\sigma p-\sigma p_o)$ in Figure 11. Study of Figure 10 indicates that the value of σp_o was negligible up to a relative density of 35 percent and was less than 0·20 kg/cm^2. But (σp_o) increased with a rapid rate as the relative density increased further. The mathematical relation is given by the equation :

$$\sigma p_o = 0{\cdot}002R/(1-0{\cdot}017\,R) \qquad ...(2)$$

This relation is independent of the size of footing and indicated that the value of σp_o reaches infinity as the relative density increases to 58·5 percent. This means no increase in ($\triangle\sigma$) beyond a relative density of 58·5 percent. But as the relative density of the soil reaches 60 percent, the soil becomes dense, and initial bearing capacity of the soil is adequate and there is no need of strengthening the soil. The conventional type of foundation may be adopted.

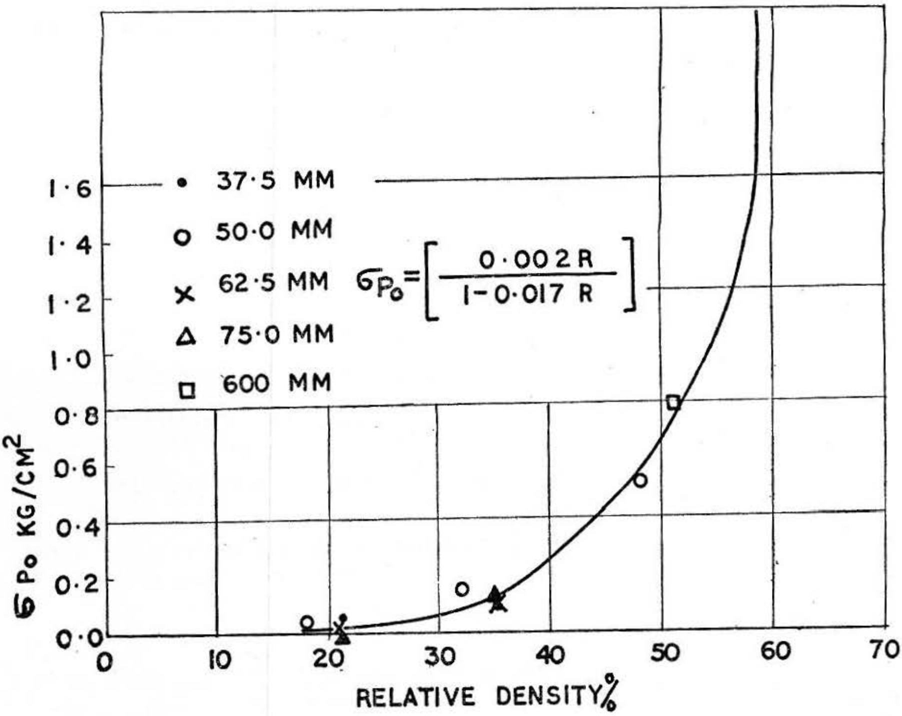

FIGURE 10 : Relation between σp_o and relative density.

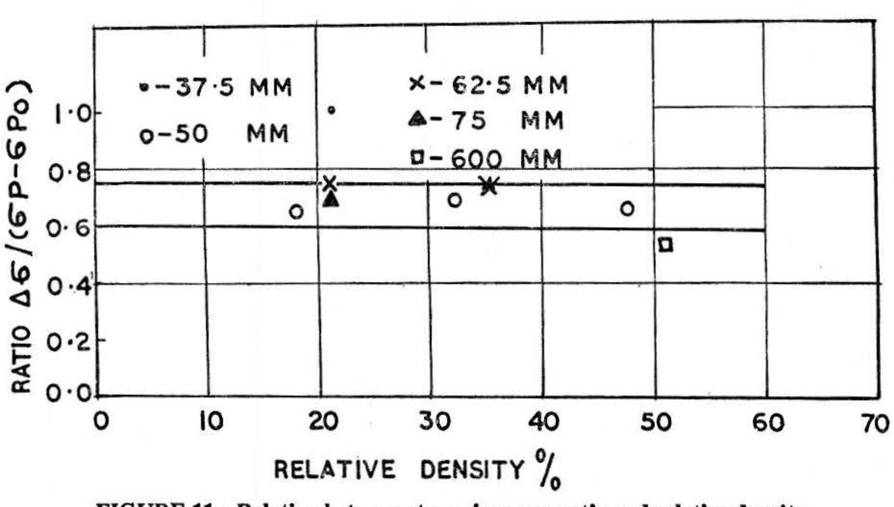

FIGURE 11 : Relation between stress increase ratio and relative density.

TABLE II

Test results of model study.

Series No.	Density	Relative Density (%)	σp_o (kg/cm^2)	Ratio $\triangle\sigma/(\sigma p-\sigma p_o)$	Width of footing (mm)	Depth of testing (mm)
1.	1·32	21	0·08	1·00	37·5	37·5
2.	1·31	18	0·05	0·65	50	50
3.	1·36	32	0·15	0·69	50	50
4.	1·42	48	0·52	0·66	50	50
5.	1·485	63	1·50	—	50	50
6.	1·32	21	0·01	0·75	62·5	62·5
7.	1·37	35	0·10	0·75	62·5	62·5
8.	1·32	21	0·00	0·69	75	75
9.	1·37	35	0·12	0·75	75	75

TABLE III

Test programme for field study.

Test No.	Size of footing (cm)	Depth of footing (cm)	Density of the soil (gm/cc)	Relative density (%)	Preloading stress (kg/cm^2)	Remarks
1.	60×300	60	1·55	51	0·0	γ_{max}. of the soil=1 97 gm/cc.
2.	-do-	-do-	-do-	-do-	1·09	γ_{min}. of the soil=1·27 gm/cc
3.	-do-	-do-	-do-	-do-	1·36	
4.	-do-	-do-	-do-	-do-	1·64	

The relation in Figure 11 indicates that the values of $\triangle\sigma/(\sigma p-\sigma p_o)$ scatter in the range of 0·65 to 1·00. No definite trend was observed with the change in the size of footings. Therefore, a minimum value of 0·60 was selected. An approximate value of increase in stress $\triangle\sigma$ for settlement greater than 12 mm is given by the equation :

$$\triangle\sigma=0{\cdot}60\left(\sigma p-\frac{0{\cdot}002\ R}{1-0{\cdot}017\ R}\right) \quad ...(3)$$

where, $R \leqslant 58{\cdot}5$ percent.

Field Study

The details of the prototype R.C.C. footings tested on preloaded soil in the field at CBRI school site, Roorkee are given in Table III. The method of preloading and testing of the footings is given earlier, Makol & Jain 1971 (a). The stress settlement relation of the tested footings is given in Figure 12 and the values of increase in stress ($\triangle\sigma$) at 12 mm settlement are plotted against preloading stress σp in Figure 13. The values of σp_o

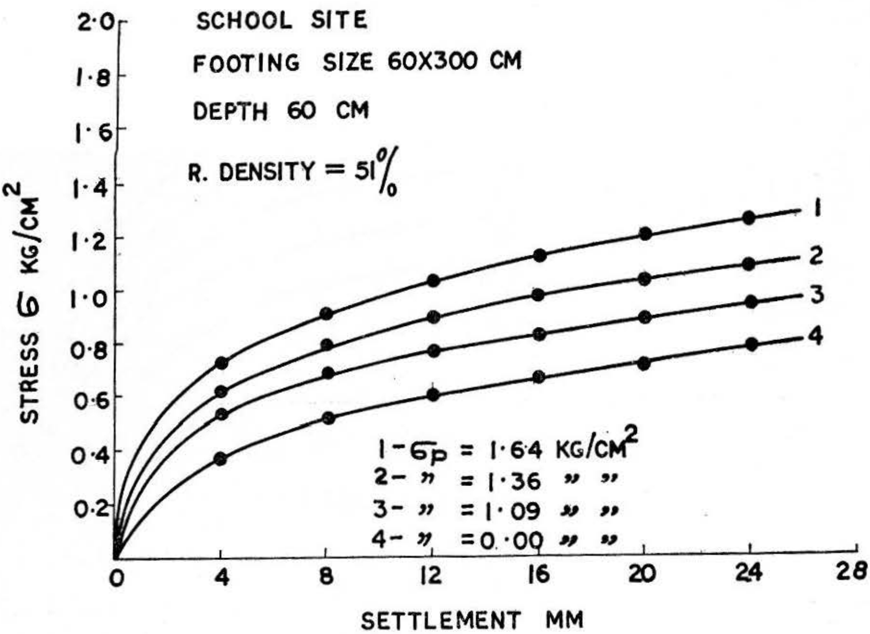

FIGURE 12 : Stress settlement relation of prototype field footing tests.

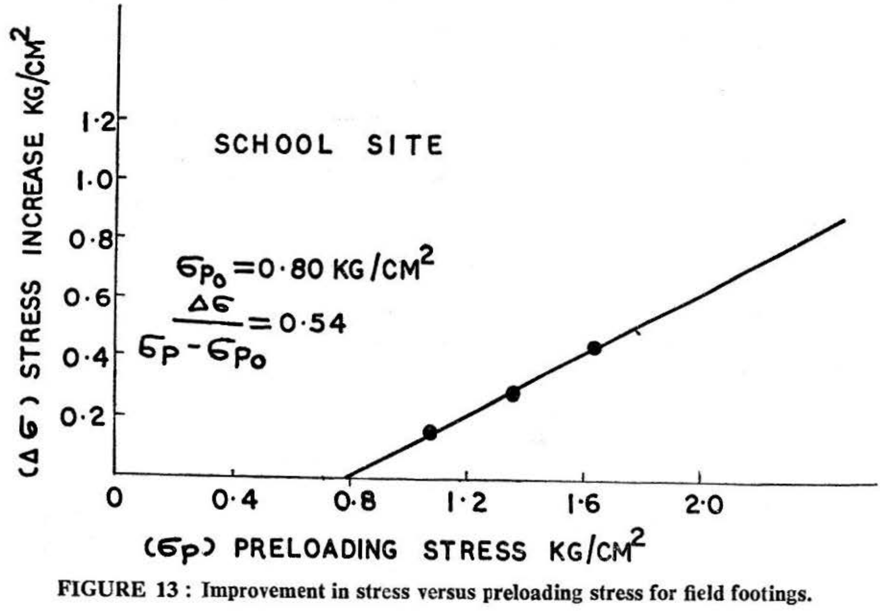

FIGURE 13 : Improvement in stress versus preloading stress for field footings.

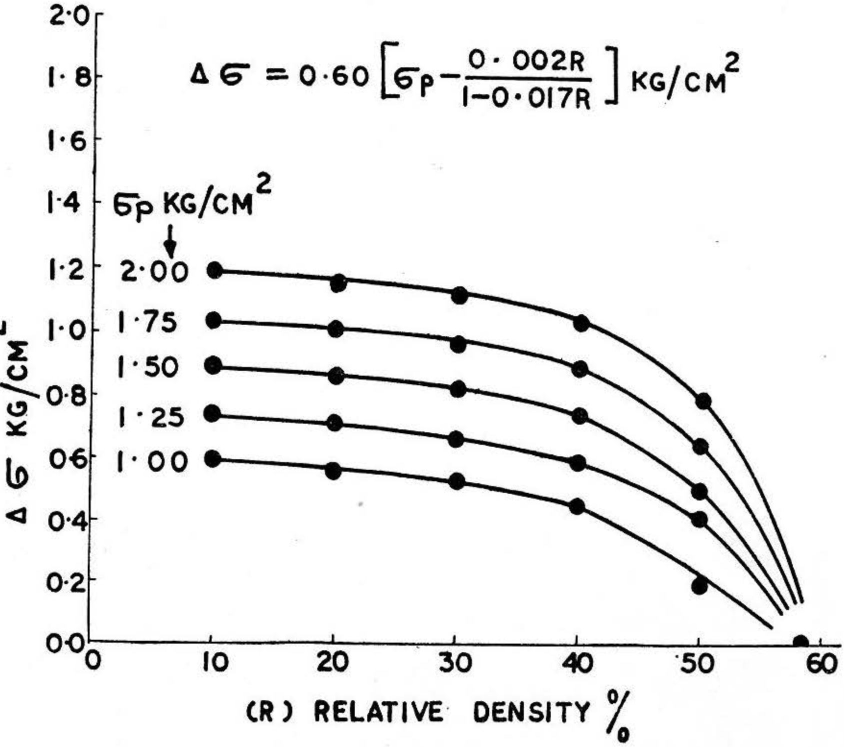

FIGURE 14 : Chart for computing preloading stress for actual preloading jobs.

and the ratio $\Delta\sigma/(\sigma p-\sigma p_o)$ were computed. These values were plotted on Figures 10 and 11 respectively. It was found that both the points satisfy the relation developed through model study. This further confirms that these relations are independent of size of footing. The equations developed by model study can be directly used for the field application.

To avoid unnecessary computations, Equation (3) is plotted in the form of a chart in Figure 14. This may be directly used to estimate the value of preloading stress required to achieve a given stress increase ($\Delta\sigma$), *if the relative density of the soil is known.*

Conclusions

(1) The value of improvement in bearing capacity ($\Delta\sigma$) of a loose soil by CBRI method for a preloading stress is constant after 12 mm settlement.

(2) The improvement increases with preloading stress and is directly proportional to effective ($\sigma p-\sigma p_o$) preloading stress.

(3) The increase is more for very loose to loose soil ($R \leqslant 40$ percent) and decreases as the soil becomes medium (R=40 to 60 percent). The increase is unappreciable for dense soil ($R \geqslant 60$ percent).

(4) An approximate value of increase in stress $\Delta\sigma$ may be estimated by the Equation (3) or chart, Figure 14.

Acknowledgement

The work described forms a part of regular research programme of Central Building Research Institute, Roorkee and the paper is published with the permission of Director. The authors are highly indebted to Prof. Dinesh Mohan for valuable suggestions and guídance in this investigation.

References

ABELEV, Y.M. & ASKALEMOV, V.U. (1957). "The Stabilization of Foundations of Structures and Loess Soils". *4th Int., Conf. SM & FE.*, Vol. 1, pp. 259-263.

DINESH MOHAN & JAIN, G.S. (1970). "Foundation for Weak Soils". *Int. Conf. SM & FE.*, Iran Shiraz, October 1970.

HAMMOND, R. (1955). "*Foundation Engineering*". Odhans Press Limited, Long Acre London.

JOHNSON, S.J. (1970). "Precompression for improving Foundation Soils". *SM & FE., ASCE*, January, 1970 pp. 111-144.

MAKOL, R.L. & JAIN, R.C. (1971 a). "Preloading a Simple Method of improving Foundation Soil". *Seminar on Foundation Problems*, January 1971, New Delhi.

MAKOL, R.L. & JAIN, R.C. (1971 b). "Preloading in Building Foundation". *Civil Engg. Construction & Public Works Journal*, Bombay.

MITCHELL, J.K. (1970). "In Place Treatment of Foundation Soils". *SM & FD., ASCE.*, January 1970, pp. 73-110.